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EFFECTS OF VIDEO CAMERA ATTACHMENT ON THE FORAGING BEHAVIOR OF IMMATURE HAWAIIAN MONK SEALS

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The Hawaiian monk seal, *Monachus schauinslandi*, is endangered (U.S. Endangered Species Act 1976), and most of the remaining population occurs on six breeding subpopulations in the Northwestern Hawaiian Islands (NWHI). French Frigate Shoals (FFS) is home to the largest subpopulation, which has declined by 70% since 1989 (Carretta *et al.* 2002). Population parameters at FFS appear consistent with prey limitation, which may be associated with decreased oceanic productivity in recent years, competition with and kleptoparasitism by other predators in the ecosystem, or depletion of prey resources by commercial fisheries (Polovina *et al.* 1994, Craig and Ragen 1999). Chronic low survivorship of immature seals has led to an age structure that ensures further population decline (Harting 2002).

The apparent food-related decline in population has lead to increased focus on the foraging behavior and diet of monk seals, particularly at FFS. While adult monk seal foraging habitat and dive behavior at FFS have been studied using both satellite tags and time-depth recorders (TDRs) (Abernathy 1999), little work has been conducted on the foraging of juvenile animals. The current lack of knowledge on the foraging ecology of immature monk seals is a major impediment to developing effective conservation strategies. The use of TDRs has greatly advanced our understanding of the diving behavior of many species of air-breathing marine predators (*e.g.*, Kooyman *et al.* 1986, Boyd *et al.* 1994, Wilson *et al.* 1996), however, foraging behavior must be inferred from dive profiles, and the data is of little use for measuring foraging success and habitat use. The CRITTERCAM video system has allowed researchers to view both foraging habitat and the behavior of free-ranging animals (Marshall 1998, Heithaus *et al.* 2001, Bowen *et al.* 2002) including Hawaiian monk seals (Parrish *et al.* 2000, 2002).

Following successful use of CRITTERCAM for studying the foraging behavior of adult monk seals (Parrish *et al.* 2000, 2002), a similar study was developed for immature monk seals. Because of the relatively large size of the CRITTERCAM, it is essential to understand the extent to which the attachment of these instruments affects the behavior and survival of the individuals (Baker and Johanos 2002). Doubtless, attaching large instruments affects the swimming efficiency of the seal to some degree by increasing drag. In this paper we attempt to test the effect of camera attachment on several aspects of foraging behavior, including multiple dive characteristics, trip duration, and time spent submerged during trips. In particular, we tested if (1) CRITTERCAM footage represents normal foraging depths of immature monk seals and (2) there is evidence that carrying the CRITTERCAM alters dive performance and foraging trip duration.

This study was conducted at FFS (23°45′N, 166°15′W) in the NWHI, an open atoll with a partial barrier reef enclosing nine islets. The lagoon reaches a maximum depth of about 20 m, and the outside of the atoll is surrounded by a 70–100-m deep terrace to the north and a 30–40-m deep carbonate pavement to the south (Parrish *et al.* 2000).

A CRITTERCAM and TDR were attached to the dorsal fur of 10 immature Hawaiian monk seals. One- to three-year-old seals were captured using a hoop net, manually restrained, and sedated with diazepam. Dorsal standard lengths and axillary girths were measured while seals were sedated and devices were glued to the dorsal fur using 10-min epoxy (Devcon®, ITW, Danvers, MA). The video cameras were fusiform, 25 cm long, and 7.5 cm in diameter at their widest point, and weighed 1.08 kg in air and 0.4 kg in water (National Geographic Television, Washington, DC). The TDRs were $9.5 \times 2 \times 1.3$ cm, weighed 27 g and were programmed to sample depth (± 1.0 m) every 10 sec (Mark 7®, Wildlife Computers, Redmond, WA). VHF radio transmitters (Advanced Telemetry Systems, Isanti, MN; 52 g) were also attached to monitor the presence and absence of seals in the atoll and aid in recapture. After >3 d the CRITTERCAM was removed but the TDR was left in place until final capture 4–48 d later (Table 1).

The following variables were extracted from dive records using Dive Analysis© software (Wildlife Computers, Redmond, WA): maximum dive depth, dive duration, bottom time, and descent and ascent rates. Bottom time was defined as the dive time spent deeper than 85% of the maximum depth. The descent rate was the average rate of descent from the beginning of a dive to the beginning of bottom time; the ascent rate was the average rate from the end of bottom time to the end of the dive. The presence of the animals on land was monitored multiple times each day with both visual and radio surveys. Foraging trip duration was estimated by using visual sightings and TDR records to estimate departure and return to shore. Proportion of time spent submerged was arcsine square root transformed and all variables were compared using a paired t-test. We used Power and Sample Size (PASS)[1] software to test how large an effect we were able to detect with the sample size available when power = 0.80, $\alpha = 0.05$, and $\beta = 0.20$.

To determine if the CRITTERCAM footage was possibly representative of foraging habitat we examined two elements. The first was whether seals dived to the same

[1] HINTZE, J. 2001. NCSS and PASS. Number Cruncher Statistical Systems. Kaysville, UT. www.ncss.com.

Table 1. Axillary girth (AG), dorsal straight length (DSL) and deployment durations of seven Hawaiian monk seals fitted with CRITTERCAM (Ccam) and a time-depth recorder (TDR).

						Deployment (d)	
Year	Animal ID	Age (yr)	Sex	AG (cm)	DSL (cm)	Ccam	TDR only
2001	YY70	3	F	107	154	10	14
	YD30	2	M	95	139	3	4
2002	YD30	3	M	107	148	3	3
	YM21	1	M	95	142	7	14
	YM30	1	M	94	138	6	48
	YD17	3	F	104	157	4	19
	YD47	3	M	113	171	7	42

depths, and thus were likely able to utilize the same habitats, with and without CRITTERCAM attached. The second was whether the timing and duration of deployments led to biases in the observed foraging behavior.

Ten CRITTERCAM/TDR/VHF packages were deployed in 2001 ($n = 2$) and 2002 ($n = 8$). TDRs were removed from two animals simultaneous to the recovery of the camera as the instruments had begun to detach from the fur. A third TDR was never recovered after the camera was removed. Only animals that had complete dive records for a period with and without the camera were used for analysis (Table 1). A total of 6,019 and 20,478 dives were available for animals with and without the camera, respectively.

Two individuals began showing signs of molting while the devices were attached or within a week of their final removal. Notably, these animals' dive records revealed abrupt changes in behavior, including an almost complete termination of dive behavior and extended periods ashore (Fig. 1A, B). Because we suspected that dive behavior likely changed due to the molt and could potentially mask any negative affect of the instrument attachment, these two animals were excluded from analysis.

Maximum depth, dive duration, average descent rate, and average ascent rate did not differ between treatments (paired t-tests, $P > 0.05$) (Table 2). Though no statistically significant differences were found in these five parameters, animals generally had slower descent and ascent rates when the camera was attached. Maximum dive depth profiles are illustrated in Figure 1.

The effect of swim drag may not have been detectable on the scale of individual dives, but cumulative effects might be measurable in other parameters. Foraging trip durations and percent time submerged did not differ significantly (paired t-tests; $P > 0.05$) with the removal of the camera (Table 2).

The minimum detectable difference (MDD; %) of the seven diving and foraging elements varied widely (7% and 55%) between variables and treatments. Most observed differences were less than the MDD (Table 2).

Immature monk seals in this study did not appear to significantly modify dive behaviors when fitted with a camera. However, the small sample size, and thus low power to detect differences, means that our results should be regarded as tenta-

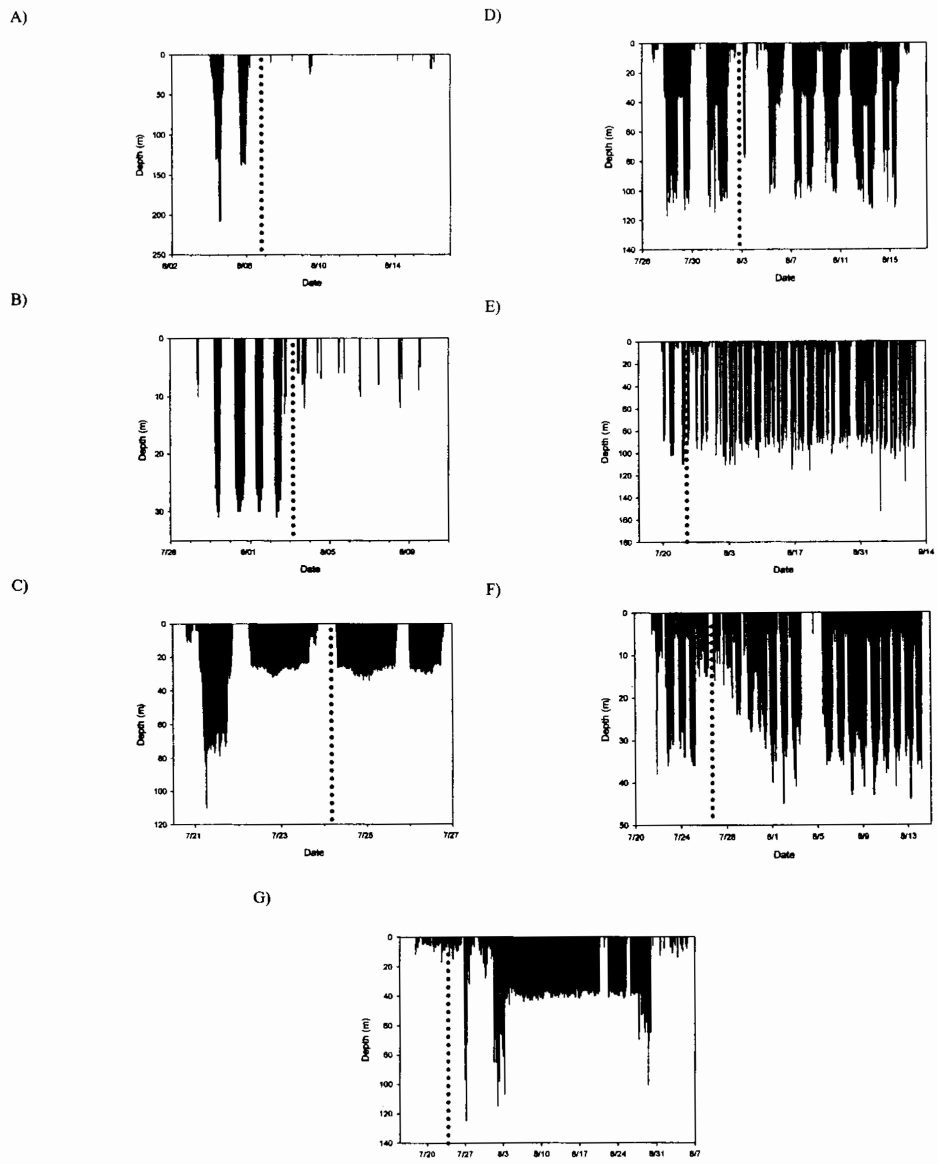

Figure 1. Plots of the maximum dive depths for all dives greater than 4-m from TDR records. Dotted lines illustrate timing of camera removal. (A) YY70, 3-yr-old female; (B) YD30 (2002), 3-yr-old male; (C) YD30 (2001), 2-yr-old male; (D) YM21, 1-yr-old male (E) YM30, 1-yr-old male; (F) YD17 3-yr-old female; (G) YD47, 3-yr-old male. Note the abrupt change in dive behavior in the latter portion of TDR deployments in animals A and B.

Table 2. Mean values (± SE) for seven dive characteristics of Hawaiian monks with (pre) and without (post) CRITTERCAM attached. Paired t-tests were used to compare the differences in means of all animals between treatments. MDD is the minimum detectable difference between the animals with and without the CRITTERCAM when $\alpha = 0.05$ and $\beta = 0.20$, and OD is the observed difference.

	Animal ID						Detectable diff.	
	YD30	YD17	YM21	YM30	YD47	Mean	MDD	OD
Max depth (m)								
pre	31.3 (0.8)	18.4 (0.5)	51.7 (1.4)	57.0 (0.7)	5.1 (0.1)	32.7 (0.5)	32%	11%
post	24.4 (0.3)	20.5 (0.2)	44.7 (0.8)	58.7 (0.9)	27.2 (0.2)	35.2 (0.2)		
Dive duration (min)								
pre	5.2 (0.2)	5.9 (0.1)	7.9 (0.2)	6.6 (0.1)	3.8 (0.2)	5.9 (0.1)	7%	3%
post	4.8 (0.1)	5.5 (0.2)	7.1 (0.3)	6.7 (0.1)	4.6 (0.1)	5.7 (0.1)		
Bottom time (min)								
pre	3.7 (0.1)	4.2 (0.1)	5.2 (0.2)	3.7 (0.1)	1.5 (0.1)	3.7 (0.2)	13%	0%
post	3.7 (0.1)	3.8 (0.1)	4.58 (0.1)	3.9 (0.1)	2.5 (0.2)	3.7 (0.1)		
Avg descent (m/sec)								
pre	1.7 (0.1)	1.4 (0.1)	1.3 (0.2)	1.38 (0.2)	0.3 (0.1)	1.2 (0.2)	38%	25%
post	1.9 (0.3)	1.4 (0.1)	1.3 (0.1)	1.6 (0.1)	1.4 (0.1)	1.5 (0.1)		
Avg ascent (m/sec)								
pre	1.6 (0.1)	1.1 (0.1)	1.2 (0.2)	1.0 (0.1)	0.4 (0.1)	1.0 (0.2)	17%	20%
post	1.8 (0.1)	1 (0.1)	1.2 (0.1)	1.1 (0.1)	0.7 (0.1)	1.2 (0.2)		
Trip duration (h)								
pre	32 (5)	22 (2)	49 (6)	21 (1)	13 (2)	27 (4)	21%	7%
post	26 (5)	23 (3)	51 (4)	22 (2)	22 (2)	29 (3)		
Time sub. (%)								
pre	71.2	68.0	36.4	39.6	21.9	47.4	43%	19%
post	55.4	68.6	40.9	66.1	51.0	56.4		

tive. Differences in means across all individuals between treatments were small. The patterns of differences between treatments, for many of the measures, were not unidirectional, thus decreasing the likelihood that there are differences along the lines one would predict. In a study of adult male harbor seals, *Phoca vitulina*, Bowen *et al.* (2002) similarly suggested that effects of camera attachment on the behavior of seals were minor over the few days that cameras were deployed. However, it is important to note that some findings in this study may warrant special attention later. For example, trends in ascent and descent velocity suggest that animals may swim slower with the camera attached, perhaps reflecting an increased cost of transport. These trends should be further examined as future deployments increase sample size and statistical power.

An increase in the cost of transport and decrease in prey capture caused by the attachment of devices can serve to increase time at sea (Boyd *et al.* 1997, Hull 1997). In this study, we found no significant differences in foraging trip duration between treatment and control periods. Boyd *et al.* (1997) found that foraging trip duration of instrumented animals increased over the length of the study; therefore, longer deployments of CRITTERCAM on monk seals might produce the same trend.

The lack of significant differences between mean dive depths and similar distribution of dive depths between treatments indicate that animals would be able to use similar habitats with or without CRITTERCAM attached. However, there are two issues to be considered when designing and analyzing future CRITTERCAM and TDR studies. Two monk seals in this study appeared to modify their foraging behavior near the onset of their molt. For example, YD30 showed similar behaviors between treatments in 2001 (Fig. 1C), but in 2002 demonstrated an abrupt change in dive behavior (Fig. 1B). Monk seals, as well as other phocids, return to and remain on shore for the majority of their molt (Kenyon and Rice 1959, Slip *et al.* 1992, Worthy *et al.* 1992, Hindell *et al.* 1994). Perhaps due to the energy cost and physiological processes associated with a catastrophic molt, foraging behavior may be altered several days or weeks before any physical indicators of molt can be observed. To the extent that dive behavior is altered by the molt, measurement of any dive behavior during this time will probably misrepresent normal foraging.

The second issue involves the duration of the camera's deployment. Animal YD47 did not molt, but showed marked differences in several dive parameters when fitted with CRITTERCAM (Table 2, Fig. 1E). YD47's dives rarely exceeded 20 m in depth while the camera was attached, whereas after the camera was removed most dives were to a depth of 50 m. Video from the CRITTERCAM revealed some shallow water searching behavior and few capture events of prey within FFS.[2] This behavior may have been a response to the camera attachment and once the camera was removed, the animal switched to a different foraging tactic. Alternatively, it may be that CRITTERCAM was deployed on YD47 in a period of rest between foraging trips. After removal of the camera, YD47 remained at FFS for approximately 2.5 d, after which time visual and radio detection ceased for approximately one month, indicating that the animal had departed the atoll without returning during that period. While away, the animal primarily dived to 50 m. Based on transiting time and depth contours of surrounding geographic features, this animal probably transited to Necker Island, approximately 120 km east of FFS, and foraged there. Abernathy (1999) identified similar behavior demonstrated by an adult male monk seal traveling from FFS to Necker Island to feed. YD47 may forage intensively away from FFS, returning to rest, socialize, and lightly feed. Short-duration CRITTERCAM deployments may not adequately represent foraging of animals that make such distant and extended foraging trips alternating with non-foraging periods at the atoll.

Our preliminary findings suggest that there is little effect from short-term attachment of the camera. However, TDR records should be collected after future CRITTERCAM deployments to continue evaluation of potential impacts with increased statistical power. This will be particularly important if deployment times are extended.

[2] PARRISH, F. A., G. J. MARSHALL, M. HEITHAUS, S. CANJA, B. BECKER, R. BRAUN AND G. A. ANTONELIS (in review). Comparison of immature and adult male Hawaiian monk seals foraging behavior and prey assessment at French Frigate Shoals, Hawaii.

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